3.3 Dynamic Radar Cross Section Sensitivity Analysis

The radar target signature of rotary wing aircraft is the combined signature of the aircraft fuselage, the rotor blades, and the rotor blade fuselage interactions. The uniqueness of the radar signature of rotary wing aircraft is that the apparent radar cross section is time variable at any given viewing aspect. The time variance of the RCS, due to rotor blade motion, creates a spectrum of RCS amplitudes over a range of doppler frequencies which is dependent upon the rotor blade rotational velocity, the radial speed of the aircraft, and the radar frequency. This time varying signature is present even when the target has zero velocity relative to the observing radar. If the target is moving, the doppler-shifted signature includes both the rotor blade and fuselage signature.

A doppler radar can detect both moving and hovering rotary wing aircraft because of the doppler frequency-shifted signature due to the rotor blades and rotor blade interaction with the aircraft fuselage.

In ALARM, the dynamic radar signature of a rotary wing aircraft is represented in two parts, the doppler frequency/amplitude spectrum of the rotor blades and rotor blade interaction with the fuselage, and the static cross section of the fuselage. If the target is moving, the doppler spectrum of the rotary elements is further shifted as a function of the relative velocity of the aircraft. The dynamic and static aircraft signatures are inputs to the model. The measured or estimated target doppler-shifted signal amplitude return is calculated to account for the propagation losses and is processed through the MTI or doppler filters of the simulated radar in order to determine if the signal-to noise ratio exceeds the detection threshold.

For radars having MTI or doppler frequency processors, ALARM uses the RCS input values at discrete frequency increments across the doppler frequency spectrum produced by the rotor blade motion. At each frequency increment, the signal amplitude is adjusted by the gain response of the MTI or doppler filter at that frequency. The total signal return, after doppler processing, is the summation of each incremental signal response over the entire frequency spectrum presented by the rotary wing target. Because of the non-uniform frequency response of the doppler processors, the integrated signal over the doppler signature spectrum may be sensitive to the frequency resolution of the input doppler signature.

3.3.1 Objectives and Procedures

The objective of the sensitivity analysis is to determine the impact of the frequency resolution of the dynamic RCS input values on (1) the doppler-processed signal calculated by the model and (2) the maximum target detection range.

At the function level the MOE is the difference in the signal level, after doppler processing, as a function of the frequency resolution of the rotor doppler input RCS. A difference of greater than 3.0 dBm in the doppler-filtered signal level relative to the baseline case will be considered significant. At the model level the MOE is the change in maximum target detection range as a function of frequency resolution of the input rotor doppler RCS. A difference of greater than 5% in the normalized mean target detection range, relative to the baseline case, will be considered significant.

Input rotor blade RCS tables for frequency resolutions of 200 Hz, 1000 Hz, and 4000 Hz were developed to conduct both the function-level and model-level analyses. Measured rotor blade RCS data, for an unidentified target, was normalized to a 1.0 square meter target level and then used to create the input dynamic RCS tables. Plots of the rotor blade RCS vs. doppler frequency at the three resolutions used for the analyses are shown in figures 3.3-1, 3.3-2, and 3.3-3. The 200 Hz table is designated the baseline case, since this was the resolution of the original data used to build the tables. The 1000 Hz and 4000 Hz resolutions were selected after experimentation showed no impact in the MOEs occurred for smaller resolutions.

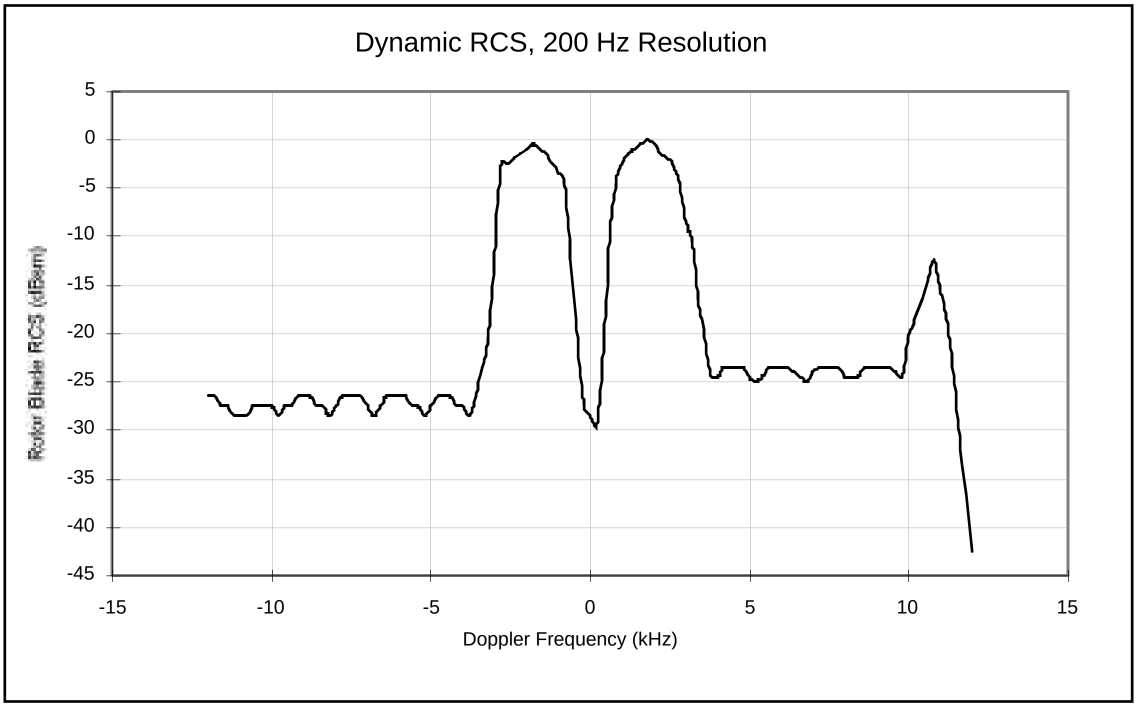

Figure 3.3-1 Rotor Doppler RCS, 200 Hz Frequency Resolution

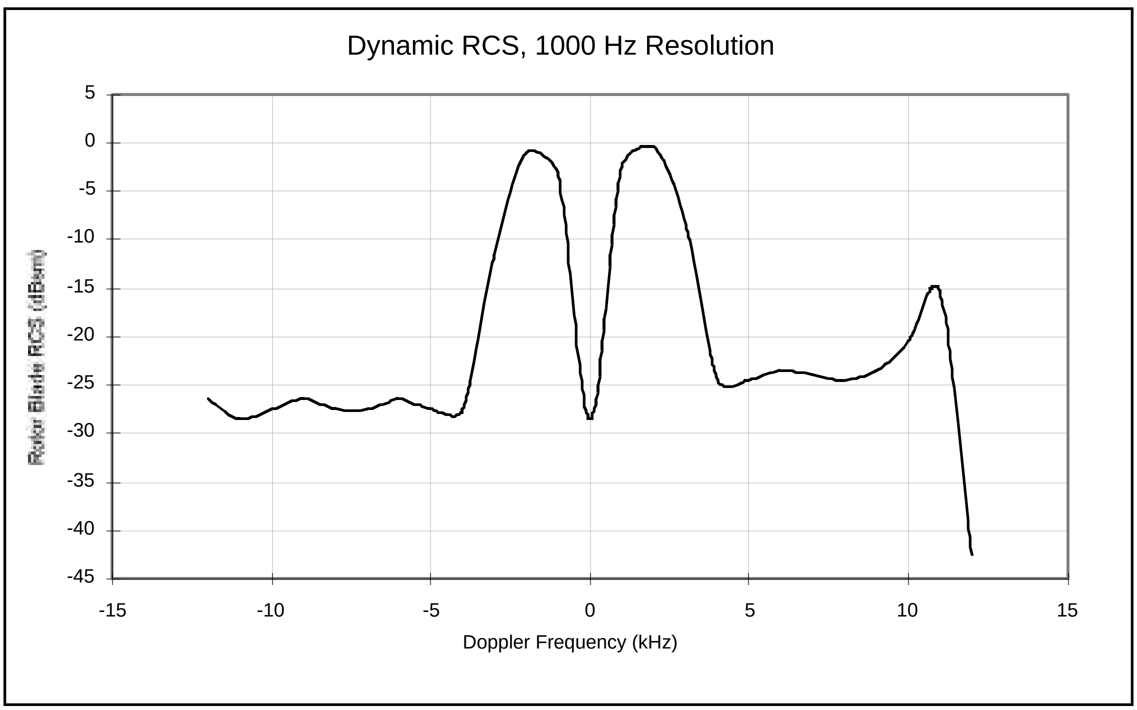

Figure 3.3-2 Rotor Doppler RCS, 1000 Hz Frequency Resolution

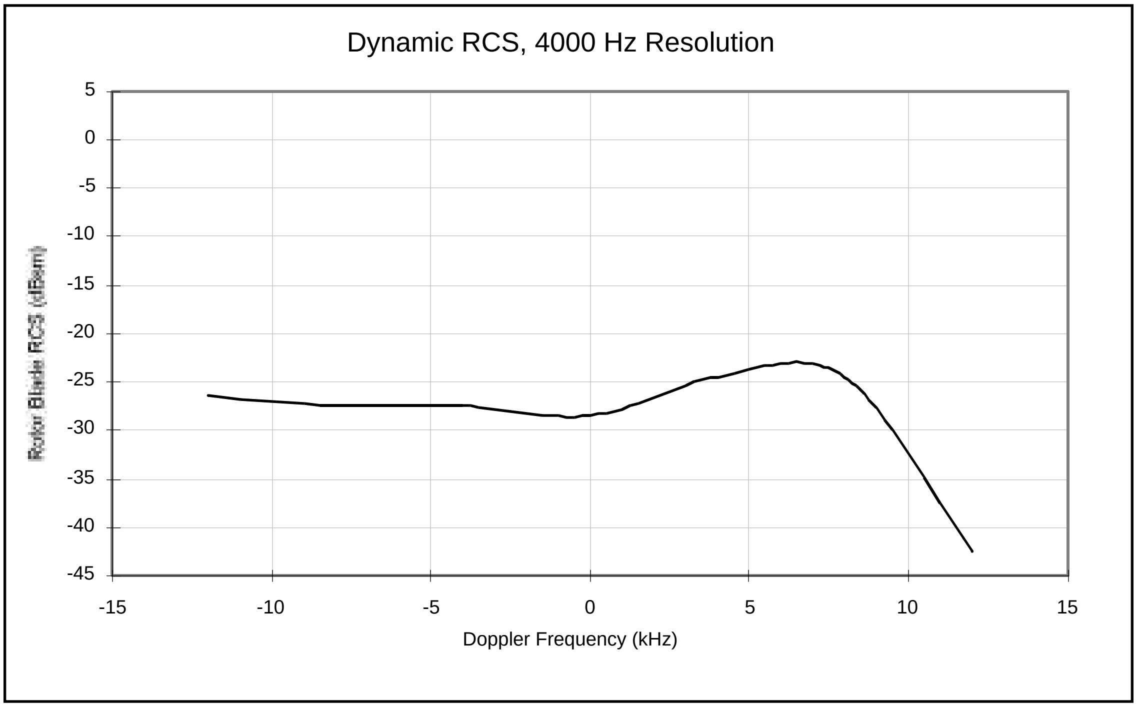

Figure 3.3-3 Rotor Doppler RCS, 4000 Hz Frequency Resolution

The procedure for the function-level sensitivity analysis is to run ALARM in Flight Path mode for the three doppler frequency signature resolutions, using a radial target flight path, target speed of 30.0 m/sec, and target altitude of 500 ft. Differences in the received doppler-processed signal for the three cases are then compared.

For the model-level analysis, ALARM is run in Contour Plot mode for a hovering target at an altitude of 500 ft, using doppler rotor blade RCS resolutions of 200 Hz, 1000 Hz, and 4000 Hz. The impact of dynamic RCS frequency resolution on target detection range is then assessed.

Table 3.3-1 identifies the specific parameters varied, and the output variables recorded, during each ALARM run.

Table 3.3-1 ALARM Runs for Dynamic RCS (Rotor Doppler) Sensitivity Analyses

Sensitivity Parameter	Analysis Level	Input Variable	Range of Variation	Output Variable	Test Case Description
Rotor (Dynamic) RCS Resolution	FE	NSPECT	**121** entries (200 Hz/entry); 25 entries (1000 Hz/entry); 7 entries (4000 Hz/entry)	SIGBLD	Run ALARM in Flight Path mode using dynamic RCS data; flight path offset= 0 km; target body RCS= 1.0 m^2; target speed= 30 m/sec.
		DOPKHZ(I)	Frequency obtained by removing values from the baseline table		
		BCSINP	Normalized rotor doppler RCS signature		
	Model	NSPECT	**121** entries (200 Hz/entry); 25 entries (1000 Hz/entry); 7 entries (4000 Hz/entry)	SIGTOI	Run ALARM in Contour Plot mode using dynamic RCS data; target body RCS= 1.0 m^2; target speed= 0 m/sec (hovering target).
		DOPKHZ(I)	Frequency obtained by removing values from the baseline table		
		BCSINP	Normalized rotor doppler RCS signature		
Note: Values in **bold** indicate baseline case.					

3.3.2 Results

FE Level: Figure 3.3-4 shows plots of the received doppler-processed signal level vs. flight path point as a function of the doppler frequency resolution of the rotor blade RCS. As can be observed, the signal increases uniformly (3.0 dBm), at all flight path points, as the frequency resolution of the RCS increases. This is not an expected result. Rather, little change or more non-uniform differences in received signal would be expected as a function of the frequency resolution of the input rotor blade RCS. Subsequent investigation of the code revealed that the signal level for each frequency interval is summed for the number of entries in the rotor RCS table. The accumulated signal should have then been divided by the number of entries. This model anomaly was reported in Model Deficiency Report 57, *Incorrect Rotor Doppler Signature Calculation*, dated 4 April 1995. The corrected model subroutine was used for the continuing analyses.

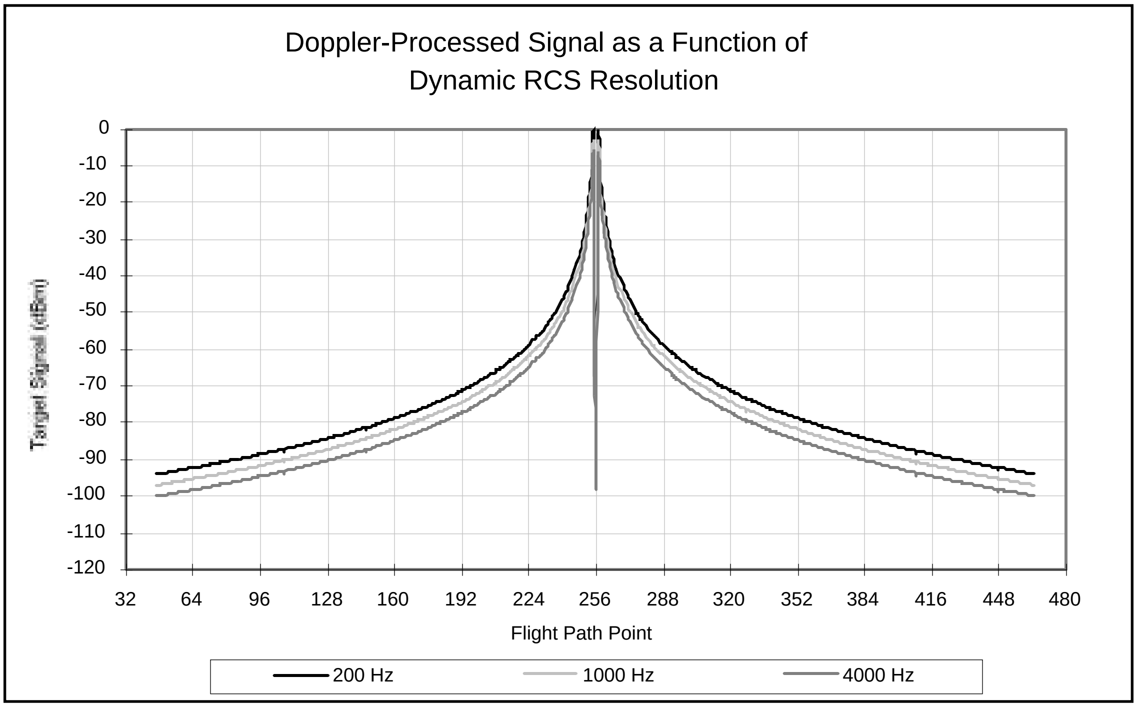

Figure 3.3-4 Doppler-Processed Signal as a Function of Dynamic Doppler Frequency Resolution (Incorrect Version of ALARM Code)

Figure 3.3-5 contains plots of the target signal received vs. numbered flight path point as a function of the frequency resolution of the input rotor blade RCS, generated with the corrected version of ALARM. As can be observed, for an input rotor blade RCS frequency resolution of 1000 Hz, there is no apparent difference in received signal relative to the case for 200 Hz frequency resolution of the rotor blade RCS. For a 4000 Hz frequency resolution of the input rotor blade RCS, there is a nearly constant difference of about 20 dBm in received signal level over most of the range of flight path points. This is expected since the peak RCS value of the rotor blade hub, the greatest contributor to the rotor blade RCS, is not contained within a resolution cell. At approximately flight path point 250, the signal level sharply dips to a value less than -130 dBm. This occurs as the target flies directly over the radar site. Since the gimbal limits of the radar antenna are approximately 85°, the antenna cannot point directly at the target and the resultant loss of antenna gain significantly reduces the received target signal.

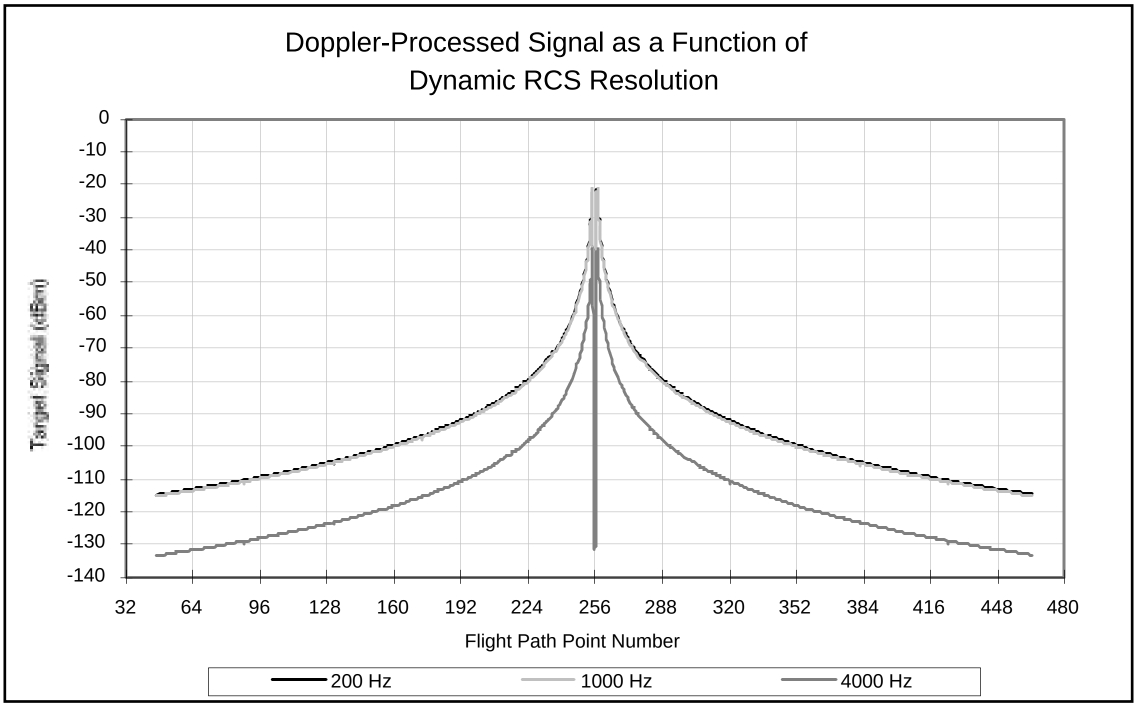

Figure 3.3-5 Doppler-Processed Signal as a Function of Dynamic Doppler Frequency Resolution (Correct Version of ALARM Code)

Figure 3.3-6, a family of plots of target detection range vs. target offset range as a function of input RCS doppler frequency resolution, shows that for the doppler frequency RCS resolutions of 200 Hz and 1000 Hz there is little difference in maximum target detection range. At 4000 Hz doppler frequency RCS resolution, there is an apparently significant difference in maximum target detection range relative to the baseline case of 200 Hz resolution. The differences in normalized mean target detection range are shown in table 3.3-2. As can be noted, at 4000 Hz RCS resolution, there is a 30% difference in the normalized maximum target detection range which exceeds the MOE significance level.

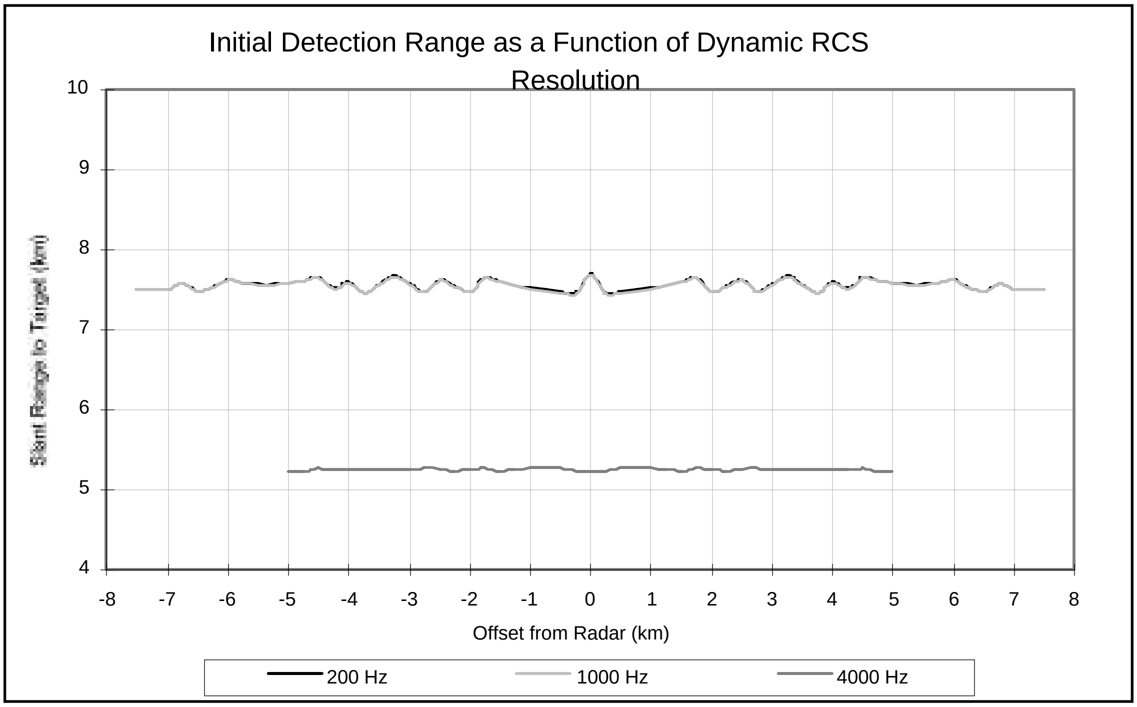

Figure 3.3-6 Initial Target Detection Range as a Function of Rotor Doppler RCS Resolution

Table 3.3-2 Differences in Mean Target Detection Range as a Function of Rotor Doppler RCS Resolution

RCS Resolution (Hz)	Mean Range (m)	σ (m)	Normalized Mean Difference	% Change
200 (Baseline)	7.55	0.06	-	-
1000	7.55	0.06	-0.00	-0.08
4000	5.25	0.01	-0.18	-30.55

As a result of the sensitivity analysis, it is apparent that the doppler frequency resolution of the rotor blade RCS can have a significant impact on the model-predicted target detection range. However, for the dynamic RCS data that was used for this evaluation, it was necessary to increase the resolution to 4000 Hz before there was a significant impact. On review of the input data (figures 3.3-1, 3.3-2, and 3.3-3), it can be observed that at 4000 Hz data resolution the RCS contributions of the rotor hub, the principal rotor blade specular point, is not included as a data point. Since each rotary blade vehicle type will have a unique signature, it is not possible to assign a generally applicable frequency resolution measurement requirement. Variations in the rotor blade speed and radar frequency will shift, expand, or compress the doppler frequency spectrum of the rotor blade RCS which adds further uncertainty to the required measurement accuracy.

3.3.3 Conclusions

ALARM uses dynamic RCS data as an input to the model so it is not essential to collect dynamic RCS data to validate this specific function. However, for validation of other functions and for overall model validation measured dynamic RCS data will be required. The doppler frequency resolution requirements for collection of rotor blade measurement cannot be explicitly defined since the rotor blade RCS of each vehicle type will be unique. Nevertheless, it is important that the frequency resolution, when measuring the dynamic RCS, is adequate to assure that all major specular reflectors of the rotor blade are included within the measured data. This indicates that the dynamic RCS of the rotor blade should be measured at the highest resolution that is practical. In application of the measured data as model input, the resolution can be user defined by reviewing the data and selecting a frequency resolution that assures that all major specular reflectors are included.